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The Effect of Argumentation-Based Teaching Supported by Concept Cartoons on Pre-Service Biology Teachers' Ability to Translate Chemical Representations About Basic Chemical Concepts

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Abstract

This study aims to investigate the effect of argumentation-based teaching supported by concept cartoons on pre-service biology teachers' conceptual understanding of basic chemistry concepts and their skills of transition between chemical representations. In this study, mixed methods were used as a research design; particularly, a special type of embedded design, a one-phase experimental embedded pattern design, was applied. The sample consisted of pre-service biology teachers studying at the Faculty of Education at a university in western Türkiye. Concept cartoons were prepared by the researchers, and the instruction lasted for nine weeks. In this study, quantitative data were collected through multiple-choice questions on chemical representations prepared by Gkitzia and colleagues (2020), and qualitative data were collected through interviews with students about these questions. We used the SPSS 23 package program for quantitative data analysis, and content analysis for qualitative data analysis. The study found that students correctly interpreted the submicroscopic drawings of substances after instruction, used symbolic representations without errors, and successfully transitioned between chemical representations. The findings of the study emphasize that the role of concept cartoons in the argumentation process is critical, especially in teaching abstract concepts.

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Introduction

Chemistry education is based on learning fundamental concepts that enable students to understand the structure and behavior of matter. Concepts such as atom, molecule, ion, element, compound, and solution form the language of chemistry; however, the literature indicates that students experience difficulties in learning these concepts and have various misconceptions (Haidar & Abraham, 1991; Devetak et al., 2009; Harrison & Treagust, 1996). For example, the perception of the atom as an indivisible unit, confusion between the concepts of ions and molecules, or misclassifications in the pure substance–mixture distinction are some of the issues that hinder students' conceptual understanding (Taber, 2009; Naah & Sanger, 2012). Similar difficulties are observed in solution chemistry; students often interpret dissolution as a chemical change and make mistakes in distinguishing between physical and chemical changes (Eilks et al., 2007; Kingir et al., 2013). These types of misconceptions arise from an inability to translate the different levels of representation in chemistry (macroscopic, microscopic, symbolic) (Johnstone, 1991).

The capacity to shift among representations is essential in the field of chemistry. Students who can connect macroscopic observations, symbolic equations, and submicroscopic explanations have a better grasp of ideas (Kozma & Russell, 2005). Nonetheless, studies indicate that students frequently encounter difficulties during this transition, and the cultivation of representational competence is a progressive endeavour (Gkitzia et al., 2020; Nyachwaya & Wood, 2014). Consequently, it is essential to create educational settings that integrate multiple representations in a cohesive manner to facilitate conceptual comprehension.

In this context, the argumentation approach is seen as a prominent teaching strategy. Argumentation based on Toulmin's (1958) model promotes scientific thinking by enabling students to support and justify their claims with evidence. Literature has shown that argumentation enhances students' conceptual understanding, critical thinking, and understanding of the nature of science (Aydeniz & Doğan, 2016; Giri & Paily, 2020; McDonald, 2017; Romero Ariza et al., 2024). Studies in the context of chemistry have shown that argumentation-based teaching is effective in reducing misconceptions and supporting meaningful learning on topics such as acids and bases, gases, chemical equilibrium, and organic mechanisms (Aydeniz et al., 2012; Lieber & Graulich, 2022).

Concept cartoons stand out as an important tool in the application of argumentation. These visual materials, which are based on everyday life situations and open up different perspectives for discussion, make alternative concepts visible for students and encourage conceptual conflict by creating a discussion environment (Naylor & Keogh, 2013). They can be used to improve students' representational competence by allowing for the simultaneous discussion of the macroscopic, microscopic, and symbolic levels of a concept in chemistry education.

Recent research indicates that argumentation, multiple representations, and scientific reasoning skills develop in parallel and that there are significant positive relationships between these dimensions (İnan et. al., 2025). Studies conducted specifically using the Science Writing Heuristic (SWH) approach have shown that the connection between the quality of argumentation and representation levels in pre-service teachers' written reports is strengthened, and that blended learning environments further support this development. These findings suggest that argumentation processes can play a critical role in developing students' ability to transition between chemical representations, and that this effect can be further enhanced when supported by visual tools. However, studies directly examining the impact of argumentation on the ability to transition between chemical representations in the literature are limited (Ramadhani et al., 2023; Yaman, 2020). The current findings indicate that argumentation encouraged students to refer to multiple representations, and the symbolic level served as a bridge between macroscopic and microscopic connections. However, this relationship needs to be examined in depth through visually rich materials structured like concept cartoons. This research aims to fill this gap. The main objective of this study is to investigate how the argumentation method supported by concept cartoons affects pre-service biology teachers' conceptual understanding of basic chemistry concepts, and particularly their ability to transition between chemical representations. In this context, the research question has been determined as follows:

- How does the argumentation method supported by concept cartoons affect pre-service biology teachers' ability to transition between chemical representations?

Literature Review

Students' Difficulties with Basic Chemistry Concepts

A lot of research has shown that students have a lot of trouble grasping the basic ideas that make up chemistry. To explain the structure and behavior of matter, it is essential to comprehend ideas like atoms, molecules, ions, elements, compounds, and solutions. However, it is observed that students frequently have misconceptions during the learning process of these concepts (Haidar & Abraham, 1991; Devetak et al., 2009). For instance, research on the idea of the atom has revealed that students view it as an indivisible, concrete unit (Harrison & Treagust, 1996), that atoms and molecules can be seen under a microscope, that their weight and volume vary depending on conditions, and that atoms other than hydrogen and oxygen can be found in water molecules (Griffiths et al., 1992). Similarly, misconceptions like thinking that ionic compounds have a molecular structure or conflating the ideas of molecules and ions have also been widely documented in the literature (Nakhleh, 1992).

Another thing that students often misunderstand is the idea of pure substance. According to Gabel (1993), students struggle to differentiate between elements and compounds, especially when it comes to categorizing common compounds like water as elements. In addition, Naah and Sanger (2012) found that about one-third of high school students that homogeneous mixtures were pure substances and water was an element. Taber (2009) noted that students tend to limit pure substances to elements only. According to Nuic and Glazar's (2023) research, middle school students categorized pure substances and mixtures based more on their experiences in daily life than on scientific definitions. This resulted in misconceptions such as thinking of sugary water as a mixture or air as a pure substance just because it contains oxygen. Similarly, Arini et al. (2025) reported that students experienced various difficulties in understanding the concepts of elements, compounds, and mixtures at the submicroscopic level; that they were actually defining elements by describing a compound as "a large number of the same atoms coming together"; that they made errors in distinguishing between elements and mixtures by drawing molecular shapes in different sizes; and that they thought of mixtures as fixed structures like elements or compounds.

Similar conceptual difficulties are apparent in the field of solution chemistry. Students reportedly do not understand dissolution as a physical process and instead think of it as a chemical reaction (Pinto et al., 2023). They also have trouble explaining physical-chemical changes (Adbo & Taber, 2009; Akgun & Gonen, 2004; Kingir et al., 2013; Papageorgiou et al., 2013). For example, Akgun and Gonen (2004) determined that students expressed the dissolution of sugar in water as a chemical change, believed that the recovery of sugar could not be achieved through physical means but only through chemical means, and decided whether a physical or chemical change was reversible or not. Smith and Metz (1996) asserted that students encounter challenges in comprehending the behavior of ionic compounds in aqueous solutions. In their 2023 study on the dissolution of oxygen in water, Pinto et al. found that students often think of dissolution as a chemical reaction, think that gases don't dissolve in water, and are very confused at the atomic-molecular level. It is posited that such conceptual misunderstandings stem from inadequate or erroneous organization of the various representation levels of chemistry (macroscopic, microscopic, symbolic). To address these misconceptions, the importance of integrating multiple representations into the learning process has been emphasized (Talanquer, 2022; Tsaparlis, 2009). Recent systematic review studies indicate that these misconceptions continue to endure in the present day. Suparman et al., (2024) analyzed 348 studies published from 2006 to 2021 and discovered that students persisted in holding analogous misconceptions, particularly regarding the concepts of atoms, molecules, ions, and solutions. The study revealed that misconceptions were widespread across different educational levels, including the incorrect categorization of pure substances and mixtures, the conflation of molecular and ionic concepts, the erroneous belief that ionic compounds have a molecular structure, and the misinterpretation of saturation-solubility limits in solutions. These findings illustrate that difficulties with fundamental chemistry concepts continue to be a substantial barrier to students' learning processes, both historically and currently.

Multiple Representations and Transfer Skills in Chemistry Education

Learning abstract ideas is an important part of chemistry education (Farheen & Lewis, 2021). While symbolic and mathematical representations are often emphasized in lectures, macroscopic properties such as color change, temperature, or pH are highlighted in laboratory settings (Prilliman, 2014). This situation leads to the submicroscopic scale being overshadowed and students experiencing difficulties in understanding chemical phenomena. For meaningful learning of concepts, it is critically important to visualize processes at the submicroscopic level, in addition to macroscopic and symbolic representations (Kozma & Russell, 2005). Chemical representations play a central role in representing both the observable and atomic/molecular-level aspects of chemical events (Hoffmann & Laszlo, 1991). These representations form the "language" of chemistry, enabling concepts to be explained at different levels (Wu & Shah, 2004). For example, an equation (symbolic) encodes the relationship between a color change in the laboratory (macroscopic) and the interaction of ions (submicroscopic). Therefore, focusing on a single type of representation is insufficient; students' ability to transition between macroscopic, microscopic, and symbolic representations serves as a critical bridge for conceptual understanding (Taber, 2009; Kozma & Russell, 1997).

Research shows that students often have trouble making this transition (Gkitzia et al., 2020; Jaber & Boujaude, 2012; Martini, 2021; Nyachwaya & Wood, 2014; Taskin et al., 2015; Uyulgan & Akkuzu-Güven, 2022). Gkitzia and colleagues (2020) contended that high school students display limited competence in navigating the three levels of representation, with university students similarly exhibiting shortcomings in this domain. Martini (2021) demonstrated that students excelled in certain symbolic representation tasks while encountering difficulties with concepts such as reversible reactions and exothermic processes, highlighting deficiencies in their comprehension of symbolic representations.

The literature suggests that representational competence, defined as the capacity to create, interpret, and translate various forms of representations, develops progressively (Gurung et al., 2022; Hilton & Nichols, 2011). Therefore, explicit instructions and focused pedagogical approaches are advised to cultivate these competencies in learners (Danin & Kamaludin, 2023; Langitasari et al., 2024; Santoso et al., 2024). Studies show that incorporating multiple representations into the learning environment significantly improves conceptual understanding and inter-representation knowledge transfer (Murni et al., 2022; Santoso et al., 2024).

Additionally, bridging representations (Pham & Tytler, 2022), modelling workshops (Stieff et al., 2016), and computer-based visualisation tools (Hu et al., 2024; Stieff, 2011; Wu et al., 2001) have also been found to be effective in enhancing representational competence. For instance, Hu et al. (2024) showed that computer simulations helped middle school students better understand the particulate nature of matter and how to switch between chemical representations. Results showed that students made substantial progress, especially in the transition from macroscopic to submicroscopic, whereas they made only limited progress in the transition from symbolic to submicroscopic.

Talanquer (2022) emphasized the importance of teachers considering the complexity of reasoning with chemical representations and employing strategies that facilitate students' transitions between different types of representations. Yaman (2020) stated that engaging students in argumentation-based inquiry processes improves their ability to use, connect with, and reflect on multiple levels of representation, enabling them to gain representational competence in written arguments over time. Overall, the literature indicates that developing students' ability to transition between chemical representations is a significant challenge in chemistry education. This challenge can be overcome through targeted instructional approaches and a deeper understanding of cognitive processes (Stieff, 2011; Nelsen et al., 2024).

Argumentation in Chemistry Education

Argumentation is defined as a powerful teaching strategy that enables students to develop scientific thinking, reasoning, and the ability to structure their ideas by providing justification, serving as an alternative to rote learning approaches (Uc & Benzer, 2021). Toulmin's (1958) model explains argumentation as the process of defending or refuting claims based on evidence. In this process, individuals exchange ideas, develop claims supported by evidence, and critically evaluate different perspectives (Yıldırır, 2020). The application of argumentation in educational settings supports students in understanding concepts more deeply, developing their questioning skills, and grasping that science is a social process (Driver et al., 2000). In the context of chemistry, argumentation enables students to examine concepts more deeply by supporting their claims with evidence and to acquire the ability to think like scientists (Abate et al., 2020).

Various teaching techniques have been developed to enable the effective application of argumentation. Among these, concept cartoons stand out; these are visual materials developed based on the constructivist learning approach, supporting students' questioning and discussion skills (Keogh & Naylor, 1999). Based on everyday situations and opening up different views for discussion, these tools make students' alternative concepts visible and encourage critical thinking by creating conceptual conflict (Balım et al., 2008). The literature indicates that concept cartoons enrich classroom discussion environments, enable students to question and restructure their existing knowledge (Keogh & Naylor, 1999), and provide a natural environment for argumentation (Driver et al., 2000).

The role of argumentation in developing students' conceptual understanding has been examined in numerous studies (Aydeniz et al., 2012; Aydeniz & Doğan, 2016; Çiğdemoğlu et al., 2017; Evrekli & Balım, 2024; Hosbein et al., 2021; Nussbaum et al., 2008; Short et al., 2009; Uzuntiryaki-Kondakci et al., 2021). The applications of these studies in the field of chemistry have generally been in the areas of acid–base (Çiğdemoğlu et al., 2017), gases (Aydeniz et al., 2012), chemical equilibrium and Le Chatelier's principle (Aydeniz & Doğan, 2016; Seyhan & Türk, 2022), and organic mechanisms (Lieber & Graulich, 2022). Researchers have found that argumentation enhances students' reasoning skills and that this development strengthens conceptual learning (Nussbaum, 2008; Scholtz et al., 2008), argumentation-based teaching is more successful than traditional teaching in reducing misconceptions (Aydeniz et al., 2012), and that it helps students understand abstract concepts through metacognitive thinking (Aydeniz & Doğan, 2016). The findings indicate that argumentation-based teaching is effective in reducing misconceptions and supporting meaningful learning. For example, Aydeniz and Doğan (2016) reported that 80% of students abandoned their misconceptions in their applications on the topic of chemical equilibrium. Evrekli and Balım (2024) found that argumentation models supported by animated concept cartoons increased students' conceptual understanding.

However, there are few studies directly examining the impact of argumentation on the ability to transition between chemical representations. Yaman (2019) demonstrated that an argumentation-based science learning approach improved middle school students' conceptual understanding and their ability to use different types of representations. The researcher, in this study conducted in a virtual laboratory environment, noted that students most frequently reported using the symbolic representation level, which served as a bridge between macroscopic and microscopic connections. Ramadhani et al. (2023) used argumentation in an online context to examine how students understand and use chemical representations. These findings suggest a significant relationship between argumentation and chemical representations.

The literature generally suggests that argumentation can enhance students' ability to transition between chemical representations. It is stressed that students who can explain a concept in different ways can turn that knowledge into stronger arguments. On the other hand, students who can defend their points with strong arguments can make more meaningful connections between chemical representations (Ramadhani et al., 2023). Therefore, supporting argumentation with different teaching tools (such as concept cartoons) has strong potential to develop both students' conceptual understanding and representational skills.

Method

Research Model

In this study, nested embedded design, one of the mixed method research designs, was used. In this design, there is a basic research method that directs the study and a second supporting approach. It is stated that this design is especially useful when researchers want to extend their experimental studies with qualitative data (Plano et al., 2008). In parallel with this explanation, the current research was designed in a single group pretest-posttest experimental design. The qualitative data of the study were obtained embedded in this approach. Therefore, while the quantitative approach is the main driver of the research, qualitative data provide a supportive, secondary perspective within the scope of the research (Ercan & Şahin, 2015).

Participants

The participants of the study consisted of 16 first-year students enrolled in the Biology Teacher Education program of a state university located in western Türkiye. The sample consisted of 2 male and 14 female pre-service teachers. Convenience sampling approach was used in the selection of the sample group. In this way, a more economical use of energy, time and cost was provided for the researcher in the study process (Yıldırım & Şimşek, 2018). All pre-service teachers are in the second semester of their education programs and are taking the General Chemistry course from the field education courses. They had never undertaken argument-based learning activities or received any specific argument-based inquiry training.

Ethical issues were prioritized in the research process. The pre-service teachers were given detailed information about the aims of the study, procedures, potential risks, benefits, and the option to withdraw at any point. Before the study, the pre-service teachers were given a voluntary consent form, and they were assured that they could leave the study at any time and that their information would remain confidential.

Data Collection Tools

A test consisting of 10 multiple-choice questions developed by Gkitzia et al. (2020) and paired interview questions related to these questions were used to determine the ability of pre-service teachers to translating between chemical representations. In multiple-choice questions on chemical representations, 3 different types of representations (macroscopic, symbolic and submicroscopic) are taken into account and students are asked to choose the other type or types of representation according to the type of representation given in the question.

In the interviews, interview questions prepared by Gkitzia et al. (2020) were used to determine the pre-service teachers' ability to translate between chemical representations. In the first question, pre-service teachers were shown pictures of 6 substances and asked to explain which particles the substances consist of, the interactions between particles, and to show the particles of these substances by drawing at the submicroscopic level. In the 2nd question, students were asked to decide whether the substances whose submicroscopic representations were given were elements, compounds or mixtures and to explain their choices. They were also asked to choose the submicroscopic representation of the gaseous substance expressed with the symbol "HI" and explain their choices. In the 3rd question, the pre-service teachers were asked to choose the macroscopic and symbolic representation of the bromine solution whose submicroscopic representation was given and explain their choices. During the interviews, the prospective teachers were expected to explain their thinking processes.

Implementation

The implementation was carried out in General Chemistry-1 course for a total of 9 weeks. In the 1st week, the students were informed about the application, interviews were conducted and then the chemical representation test was applied. In the 2nd week, the concept of argument and the characteristics of a good argument were introduced to the students through different activities ("Choose your side" and "What is an argument?" (Yıldırır, 2013). In the 3rd week, since the participants were biology students, the activity named "Euglena: Plant or Animal?" (Osborne et. al., 2004), which is available in the literature for the biology subject they dominate, was used to help the students get used to the argumentation method more easily. After the argument introduction and familiarization lessons, argumentation-based chemistry lessons were conducted (Weeks 4-8) (Table 1). Argumentation strategies (Osborne et. al., 2004) were utilized in the preparation of the activities in the argumentation-based chemistry lessons and three different chemical representations (macroscopic, symbolic and submicroscopic) were considered in the activities. In the 9th week, interviews were conducted with the students and a chemical representation test was applied.

Table 1. Activities to Encourage Argumentation in Chemistry Lessons

Week	Activities	Description
2	“Choose your side" and "What is an argument?" (Yıldırır, 2013).	The concept of argument and the characteristics of a good argument were introduced to the students through different activities.
3	Euglena: Plant or Animal? (Osborne et. al., 2004)	Since the participants were biology students, the activity named "Öglena: Plant or Animal?” which is available in the literature for the biology subject they dominate, was used to help the students get used to the argumentation method more easily.
4	“What's going on?” and "Hot-Cold"	TGA activities prepared by targeting the misconception "There are no atoms in all substances/living things (Ceylan, 2015)." were applied.
5	"Solid-Liquid-Gas"	Students were asked to show the particle structures of Ne(g), O2(g) and H2O(s) with play doughs, prepared by targeting the misconceptions "There is no space between the particles forming solids (Tatar, 2011).", "The molecules of solid substances do not move (Tsitsipis et. al., 2012)." and "When we heat a substance, the particles forming the substance expand (Brook et. al., 1984; in cited Kokkotas et al., 1998)." was applied.
	“Is it pure or not?"	In this activity, macroscopic and submicroscopic representations of substances were given together and students were asked to decide which of these substances

Week	Activities	Description
6		were pure substances by discussing them.
	"Let's match"	In this activity, students were expected to match the submicroscopic and symbolic representations of substances and explain their choices
	"Let's separate molecular elements and compounds.”	In this activity, students were expected to distinguish the elements and compounds with molecular structure whose submicroscopic representations were given, choose the correct expression, and explain their choices.
	“Let's distinguish between molecular compounds and ionic compounds”	In this activity, submicroscopic representations of substances were given and students were expected to distinguish between molecular and ionic compounds and explain their choices.
7	"Who won the competition 1?" "Who won the competition 2?"	In the 1st concept cartoon, students were asked to determine the correct submicroscopic representation of $CO_{2(aq)}$, $NaCl_{(aq)}$ and $I_{2(aq)}$ solutions and in the second concept cartoon, students were asked to determine the submicroscopic representations of $HI_{(aq)}$, $NH_{3(aq)}$ and $KCl_{(aq)}$ solutions whose symbolic representations were given and to explain their choices.
8	"Basket game"	In this activity, students were asked to discuss the accuracy of nine statements regarding pure substances and mixtures and explain their choices accordingly.

In general, in the activities, pre-service biology teachers were first asked to carry out the activities individually. Then, pre-service biology teachers were asked to share and compare their ideas by discussing in groups of 4-5 students. As a result of the discussions, the groups presented their arguments to the class with their spokes persons. During the presentations, the teacher, as a guide, encouraged the pre-service teachers to create counter arguments in a questioning way. At the end of the lesson, the arguments were evaluated through a general class discussion and the correct argument was reached.

Data Analysis

Quantitative Data Analysis

The answers given by the pre-service teachers to the test related to the abilities of transition between chemical representations were analysed and correct answers were coded as 1, incorrect and blank answers were coded as 0. In data analysis, normality analysis was performed by taking the differences of pre-test and post-test scores of the groups. Since the sample group was less than 50, the conformity of the data to normal distribution was analysed by Shapiro-Wilk normality test. According to the results of the Shapiro-Wilk test (W= 0.909; p=0.113), paired samples-t test from parametric tests were utilized to compare data. The reliability of data was checked by The Kuder Richardson-20 (KR-20) value. The Kuder Richardson-20 (KR-20) value was calculated to be 0.579 for pre-test implementation and 0.624 for post-test implementation. This result indicates that the reliability of the results is at a medium level (Salvucci et al.,1997).

Additionally, Cohen's effect size (Cohen's d) was calculated and interpreted to assess the practical significance of the findings beyond their level of significance. Effect size is a statistical measure that indicates the degree of deviation of the results obtained from the sample from the expectations defined in the null hypothesis (Cohen, 1994). As a general recommendation, Cohen (1994) states that an effect size can be defined as weak if the d value is less than 0.2, moderate if it is 0.5, and strong if it is greater than 0.8.

Qualitative Data Analysis

Content analysis was used to analyse the interview questions. Pre-service teachers' responses to the interview questions were collected through audio recordings and converted into written text. The written text was then analysed and codes were created for the students' responses. Then, categories related to the codes were created and frequency values were determined. In the last stage, the data obtained were interpreted in a way that readers could understand. It was determined that there were drawings addressing more than one code in the interviews. For this reason, in some tables, there are codes where the frequency and number of pre-service teachers are different from the total number of pre-service teachers. While presenting the findings, the pre-service teachers were coded as PS1, PS2, PS3.

Validity and Reliability

In order to increase the consistency of the analysis of the interview data, while creating categories for the data obtained, codes were also created and compared with an expert. Using the data obtained from both coders, the reliability value was determined with the coder reliability formula proposed by Miles and Huberman (1994). According to this formula, reliability was calculated as = (agreement) / (agreement + disagreement) x 100. As a result of the calculations, the percentage of agreement was calculated as 95%. It is stated that values above 80% are sufficient for inter-coder reliability (Miles & Huberman, 1994). The fact that the agreement between the coders is above 80% indicates that the reliability of the analysis is ensured. In addition, after the reliability calculation, communication was provided between the coders, the points of disagreement were reviewed, discussed and consensus was tried to be reached.

Ethical Approval

Ethical approval was taken from Science and Engineering Ethics Commission of Balıkesir University (E-19928322-302.08.01-91023).

Findings

Quantitative Findings on Pre-Service Biology Teachers' Ability to Translate between Chemical Representations

A t-test was applied to the paired samples to determine whether the difference between the group's pre-test and post-test scores was statistically significant in favor of the post-test, and the findings are presented in Table 2.

Table 2. t-Test Results of the Group's Pre-Test-Post-Test Scores

	N	Mean (X)	S.s.	s.d.	t	p
Pre-test total	16	5.8750	1.78419	15	-6.152	0.000
Post-test total	16	9.0625	1.34009			

According to Table 2, the group's pre-test score average was 5.8750, while the post-test score average was 9.0625. Furthermore, the analysis revealed that the group's pre-test standard deviation value was 1.78419 and the post-test standard deviation value was 1.34009. Based on the test results, the difference between the group's pre-test mean scores (X=5.8750) and post-test mean scores (X=9.0625) is significant at the 0.05 and 0.01 significance levels [t(15)=-6.152, p<0.01, Cohen's d=1.538]. According to Cohen (1994), this effect size indicates that the implemented activities had a high level of impact on the students' success in the relevant subject. The responses and percentages provided by the group regarding their ability to transition between chemical representations applied before and after instruction are presented in Table 3.

Table 3. Pre-Service Teachers' Pre-Test and Post-Test Responses and Their Percentages

Question	Chemical representations	Pre-test								Post-test							
		a		b		c		d		a		b		c		d	
		f	%	f	%	f	%	f	%	f	%	f	%	f	%	f	%
1	Submicroscobic -Macroscobic	16*	100	-	-	-	-	-	-	16*	100	-	-	-	-	-	-
2	Microscopic-Submicroscopic	10*	62.5	-	-	-	-	6	37.5	16*	100	-	-	-	-	-	-
3	Submicroscopic -Symbolic	14*	87.5	2	12.5	-	-	-	-	15*	93.75	1	6.25	-	-	-	-
4	Triple representation	3	18.75	-	-	2	12.5	11*	68.75	-	-	-	-	-	-	16*	100
5	Submicroscopic -Symbolic	4*	31.25	5	31.25	2	12.5	5	31.25	15*	93.75	1	6.25	-	-	-	-
6	Symbolic-Submicroscopic	-	-	16*	100	-	-	-	-	2	12.5	13*	81.25	-	-	1	6.25
7	Submicroscopic -Macroscopic	1	6.25	11*	68.75	4	25	-	-	-	-	16*	100	-	-	-	-
8	Macroscopic-Submicroscopic	-	-	8*	50	4	25	4	25	-	-	15*	93.75	1	6.25	-	-
9	Submicroscopic -Symbolic	13	81.25	1	6.25	-	-	2*	12.5	1	6.25	-	-	-	-	15*	93.75
10	Symbolic-Submicroscopic	14	87.5	-	-	2*	12.5	-	-	3	18.75	-	-	13*	81.25	-	-

(* The marked ones show the correct options of the questions.)

When Table 3 is analyzed, it is seen that all pre-service teachers were successful in both pre-test and post-test in question 1, which required determining the macroscopic representation of $Au_{(k)}$ from its submicroscopic representation. In the 2nd question, the submicroscopic representation of the element $Na_{(k)}$, whose macroscopic representation is given, should be selected. While 10 pre-service teachers answered this question correctly in the pre-test, 6 pre-service teachers chose option D and made mistakes. It was determined that the pre-service teachers who chose option D thought that the element $Na_{(k)}$ was composed of two different atoms. In the post-test, it is seen that all of the pre-service teachers gave the correct answer.

In the 3rd question, it was asked to choose the symbolic representation of $LiBr_{(k)}$ compound whose submicroscopic representation was given. While 14 pre-service teachers gave correct answers and 2 pre-service teachers gave wrong answers in the pre-test, 15 pre-service teachers gave correct answers and 1 student gave wrong answers in the post-test. The pre-service teachers who gave incorrect answers in both tests chose option B. It was determined that these pre-service teachers chose $LiCN_{(k)}$ symbolic representation for $LiBr_{(k)}$ compound and thought CN^- ion as a single atom.

In the 4th question, more than one representation of potassium chloride was given and pre-service teachers were asked to choose the correct ones. While 11 pre-service teachers gave correct answers in the pre-test, 5 pre-service teachers gave incorrect answers, and all pre-service teachers gave correct answers in the post-test. It was determined that 3 of the pre-service teachers who made mistakes in the pre-test chose option A and did not know that ionic compounds should be separated into ions when the solution is formed; 2 pre-service teachers chose option C and did not pay attention to the physical state of the ionic compound.

In the 5th question, it was asked to determine the symbolic representation of $NO_{(g)}$ gas whose submicroscopic representation was given. In the pre-test, 4 pre-service teachers answered correctly and 12 pre-service teachers answered incorrectly; in the post-test, 15 pre-service teachers answered correctly and 1 student answered incorrectly. It is understood that the incorrect pre-service teachers decided on the symbolic representation by looking at the number of molecules ($(NO)_3$ and 3NO) or the number of atoms (N_3O_3) since there were 3 NO molecules in the submicroscopic representation.

In the 6th question, the symbolic representation of the compound $HI_{(g)}$ was given and the submicroscopic representation was asked to be chosen. While all pre-service teachers answered correctly in the pre-test, 13 pre-service teachers answered correctly in the post-test. In the post-test, it was understood that 2 pre-service teachers who chose option A and 1 student who chose option D thought $HI_{(g)}$ compound as a mixture.

In the 7th question, pre-service teachers were asked to choose the macroscopic representation of a substance whose microscopic representation was given. While 11 pre-service teachers gave correct answers in the pre-test, 5 pre-service teachers gave wrong answers, and all of the pre-service teachers gave correct answers in the post-test. It is understood that 1 of the 5 pre-service teachers who gave wrong answers in the pre-test chose option A, which shows iodine gas, and 4 chose option C, which shows a mixture of Sulphur and iron, and that they did not pay attention to the presence of water molecules in the submicroscopic representation.

In the 8th question, it was asked to choose the symbolic representation of $Cl_{2(aq)}$ whose submicroscopic representation was given. In the pre-test, 8 pre-service teachers gave correct answers and 8 pre-service teachers gave incorrect answers; in the post-test, 15 pre-service teachers gave correct answers and 1 student gave incorrect answers. It was determined that 4 pre-service teachers in the pre-test and 1 student in the post-test did not know that the expression "aq" represents solvent water by choosing option C, and 4 pre-service teachers who chose option D in the pre-test thought that all molecules in the solution (Cl_2 and H_2O) were shown in the chemical formula.

In the 9th question, it was asked to choose the submicroscopic representation of saline water whose macroscopic representation was given. It is seen that 2 pre-service teachers answered this question correctly and 14 pre-service teachers answered incorrectly in the pre-test; 15 pre-service teachers answered correctly and 1 student answered incorrectly in the post-test. It is thought that 13 pre-service teachers who chose option A in the pre-test and 1 student in the post-test thought that the ionic compound did not separate into ions in the solution; 1 student who chose option B in the pre-test did not know that there should be water molecules in the solution.

In the 10th question, it was asked to choose the submicroscopic representation of $KF_{(aq)}$ solution whose symbolic representation was given. While 2 pre-service teachers gave correct answers and 14 pre-service teachers gave incorrect answers in the pre-test, 13 pre-service teachers gave correct answers and 3 pre-service teachers gave incorrect answers in the post-test. It was understood that 14 pre-service teachers who made mistakes in the pre-test and 3 pre-service teachers who made mistakes in the post-test thought that the ionic compound was not separated into ions in the solution by marking option A.

Qualitative Findings on Pre-Service Biology Teachers' Ability to Translate between Chemical Representations

Findings related to the First Interview Question

Interviews were conducted with the pre-service teachers before and after the instruction. The submicroscopic drawings (interview question 1) made by the pre-service teachers for the substances whose macroscopic representations were given during the interviews ($Na_{(s)}$, $NaCl_{(s)}$, $H_2O_{(l)}$, $O_{2(g)}$, $NaCl_{(aq)}$, and $O_{2(aq)}$) were analyzed. Examples of the drawings made during the pre- and post-instruction interviews are presented in Table 4.

Two fundamental properties are required for the submicroscopic representation of Na(s) metal. These properties are: (a) it should consist of one type of particle/circle and (b) the particles/circles should have a close arrangement (Gkitzia et al., 2020, p.315). Before instruction, drawings containing these properties:

(a) were present in 10 pre-service teachers' drawings, while errors were identified in six pre-service teachers' drawings. It was revealed that the pre-service teachers incorrectly identified the type of particle constituting the substance and drew molecules for metallic sodium

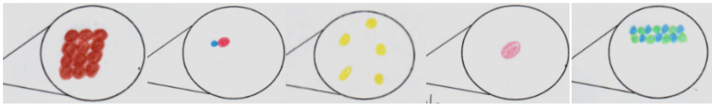
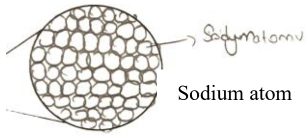
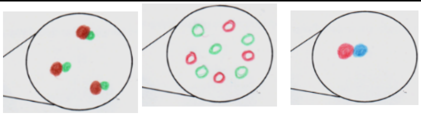
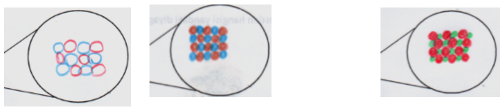
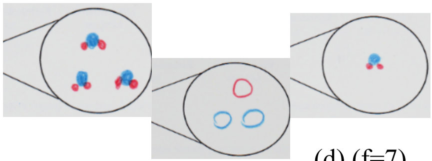
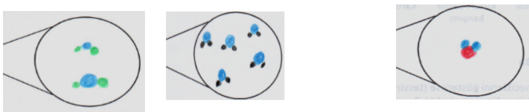
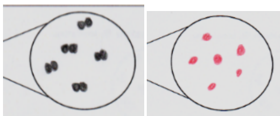
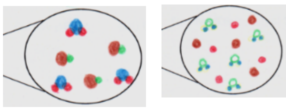
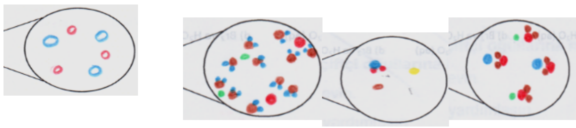
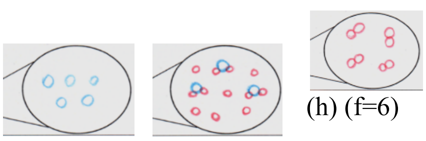
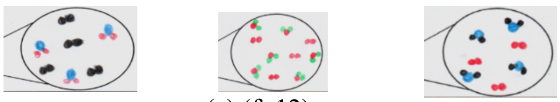
(b) they did not consider the substance to be a solid and left too much space between the particles

(c) they thought the substance was composed of a single particle

(d) and they drew two different particles and assumed that iron atoms were present in addition to the sodium atoms because of the word "metallic"

(e) After instruction, all pre-service teachers were able to accurately draw and explain submicroscopic representations of sodium metal, including the aforementioned properties of the substances.

Table 4. Sample Drawings from Pre-and Post-instruction Interviews

Matter	Pre-instruction	Post-instruction
$Na_{(k)}$	 (a) (f=10) (b) (f=2) (c) (f=2) (d) (f=4) (e) (f=2)	 (a) (f=16)
$NaCl_{(k)}$	 (b) (f=9) (c) (f=2) (d) (f=6)	 (f) (f=9) (f) (f=16) (j) (f=7)
$H_2O_{(s)}$	 (a) (f=6) (b) (f=2) (d) (f=7)	 (a) (f=15) (f) (f=1) (d) (f=1)
$O_{2(g)}$	 (a) (f=4) (b) (f=10)	 (d) (f=2) (a) (f=16)
$NaCl_{(aq)}$	 (b) (f=9) (g) (f=6)	 (a) (f=10) (g) (f=2) (k) (f=4) (h) (f=5)
$O_{2(aq)}$	 (h) (f=6)	 (a) (f=12) (i) (f=4) (i)(f=3)

The submicroscopic representation of $NaCl_{(k)}$ should contain two types of particles/circles, the particles/circles should have a close-packed, and attention should be paid to the particle size and lattice structure. None of the pre-service teachers had made a drawing that included these features before instruction, and they could not provide an explanation. It was observed that the pre-service teachers incorrectly identified the type of particles that make up the substance in their drawings, thought that the particles that make up sodium chloride were molecules or atoms (b), did not consider the substance as a solid and left too much space between the particles (c), thought that a single particle constituted the substance (d), and did not pay attention to the particle size and lattice structure (f).

After instruction, it was observed that all pre-service teachers knew that the solid sodium chloride compound was composed of ions, 9 of these pre-service teachers drew both ions at the same size (f), and 7 paid attentions to the size of the ions when drawing them (j). However, it was determined that all pre-service teachers had difficulty in making three-dimensional drawings and that they did not think that each Na+ ion would be adjacent to six Cl^{-} ions and similarly each Cl^{-} ion would be adjacent to six Na+ ions, forming a NaCl crystal in relation to the lattice structure while drawing (f, j).

In the submicroscopic representation of water, two types of particles/circles should be present, the particles/circles should have a molecular structure, and attention should be paid to the distances between particles according to the physical state of the substance. Before the instruction, these features were present in the drawings of six pre-service teachers, while errors were noted in the drawings of the other ten pre-service teachers (10). It was observed that these pre-service teachers used two types of particles in their drawings, but they thought that the particles of water were atoms (H, O) and not molecules (b), that they had the misconception that a single particle would be sufficient for the formation of water (d), and that they drew the particles at different sizes without paying attention to their size (f). In the interviews conducted after the instruction, 15 pre-service teachers made the correct drawings, and in their explanations, they stated that the substance was composed of water molecules and that the interactions between the molecules were H-bonds. It was observed that one student (PS12) drew only a single water molecule.

The submicroscopic representation of oxygen gas should have a uniform particle/circle structure, the particles/circles should have a molecular structure, and the distance between particles should be considered according to the physical state of matter. Before instruction, only four pre-service teachers produced drawings that included these properties. Ten of the other pre-service teachers believed that the particles constituting oxygen gas were atomic (b), while two pre-service teachers drew drawings thinking that oxygen gas consisted of a single molecule (d). After instruction, it was observed that all pre-service teachers accurately drew and explained submicroscopic representations of oxygen gas, including the aforementioned properties of the substances.

Three basic properties are required for a submicroscopic representation of NaCl(aq) solution. These properties are: (a) showing sodium and chloride ions, (b) showing water molecules, and (c) water molecules approaching and enveloping Na+ ions by oxygen and Cl- ions by hydrogen. Before instruction, none of the pre-service teachers could produce a correct drawing that included the above properties. An examination of the pre-service teachers' drawings and explanations revealed that nine pre-service teachers drew molecules instead of ions (b), six pre-service teachers drew ions and water molecules but did not mention ion-dipole interactions in either their drawings or explanations (g), and five pre-service teachers did not mention the existence of water molecules and did not show them in their drawings (h). After instruction, it was observed that 10 pre-service teachers demonstrated that sodium chloride solution consists of ions and water molecules, drew the ions according to their diameters, and correctly demonstrated ion-dipole interactions (a). In addition, it was observed that 4 pre-service teachers mentioned the correct particles but partially showed the ion-dipole interactions (k) and 2 pre-service teachers drew a sodium ion, a chloride ion and a water molecule (g) and made the mistake of thinking that so many particles would form the solution.

The submicroscopic representation of the $O_{2(aq)}$ solution required demonstration of oxygen and water molecules and the interactions between these molecules. Before instruction, pre-service teachers were unable to produce a correct drawing that included the above-mentioned features. An examination of the pre-service teachers' drawings and explanations revealed that 10 pre-service teachers demonstrated that oxygen gas dissociates into ions like ionic compounds when dissolved in water, or that they drew oxygen molecules atomically (b), 6 pre-service teachers ignored the existence of water molecules (h), and 4 pre-service teachers showed the oxygen atoms in the oxygen molecule and water molecule in different colors (i). After instruction, 12 pre-service teachers correctly demonstrated the submicroscopic representation of the aqueous oxygen solution (a), indicating that the substance consists of oxygen and water molecules and mentioning dipole-dipole interactions in their drawings. Furthermore, 3 pre-service teachers showed the oxygen atoms in the oxygen molecule and water molecule in different colors (i).

In the first interview question, pre-service teachers were asked to draw the submicroscopic representations of the substances and also write their symbolic representations. The symbolic representations written by the pre-service teachers were examined and common codes were determined (see Table 5).

Table 5. Symbolic Representations Written by Pre-service Teachers (Pre-Instruction)

Matter	Code	Symbolic Representation	Participant	f
$Na_{(k)}$	Inability to distinguish between particle and matter	Na	PS9, PS10, PS11, PS12	4
	Using parenthesis in the wrong place	$[Na]_{(k)}$	PS4, PS13	2
	Using incorrect charge/ coefficient/symbols	$Na^{+}Fe^{-}$	PS15, PS16	2
$NaCl_{(k)}$	Inability to distinguish between particle and matter	NaCl	PS9, PS10, PS11, PS15, PS16	5
	Using parenthesis in the wrong place	$[NaCl]_{k}$	PS13	1
	Using incorrect charge/ coefficient/symbols	NaC, $NaCl_{2(k)}$, $Na^{+1}Cl^{-1}{}_{(k)}$, $NaCl^{-}{}_{(katı)}$	PS5, PS7, PS12, PS14	4
$H_2O_{(s)}$	Inability to distinguish between particle and matter	H_2O	PS3, PS6, PS9, PS10, PS11, PS12, PS15, PS16	8
	Using parenthesis in the wrong place	$[H_2O]_{s}$	PS13	1
	Writing your physical state wrongly	$H_2O_{(g)}$, $H_2O_{(aq)}$	PS5, PS7	2
$O_{2(g)}$	Inability to distinguish between particle and matter	O_2, O, $O^{+2}{}_{(gaz)}$	PS3, PS6, PS9, PS10, PS11, PS12, PS14, PS15, PS16	9
	Using parenthesis in the wrong place	$[O]_{g}$	PS13	1
$NaCl_{(aq)}$	Inability to distinguish between	NaCl	PS9	1

Matter	Code	Symbolic Representation	Participant	f
	particle and matter			
	Using parenthesis in the wrong place	$[NaCl]_{aq}$	PS13	1
	Using incorrect charge/ coefficient/symbols	$NaH_2O_{(suda)}$, H_2ONaCl $NaHCl^-O_{2(aq)}$, Na^+Cl^-	PS4, PS10, PS11, PS14, PS15, PS16	6
$O_{2(aq)}$	Inability to distinguish between particle and matter	O_2	PS9	1
	Using parenthesis in the wrong place	$[O]_{aq}$	PS13	1
	Using incorrect charge/ coefficient/symbols	$O_2H_2O_{(suda)}$, $O_{(aq)}$, $H_2O_{2(aq)}$, O^{-3}	PS1, PS4, PS10, PS11, PS12, PS14, PS15, PS16	8

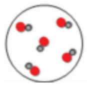
Before instruction, it was observed that pre-service teachers were most unable to distinguish between the symbolic representation of particles and substance. This incorrect representation was found to be made by four pre-service teachers for the substance metallic sodium, five for sodium chloride, eight for water, five for oxygen gas, one for sodium chloride solution (PS9), and one for oxygen gas (PS9). As seen in Table 5, it was observed that pre-service teachers with codes PS4 and PS13 made incorrect representations for the substance metallic sodium with the incorrect representation code "Using parentheses in the wrong place." Only student PS13 made incorrect representations for the other five items. Two of the pre-service teachers used different symbols for the substance metallic sodium, four for sodium chloride, five for sodium chloride solution, and seven for oxygen gas. An examination of Table 5 reveals that students with codes PS5 and PS7 wrote incorrectly the physical state of water. Three pre-service teachers incorrectly thought oxygen gas was an atom, and one student (PS9) incorrectly thought it was an ion. It was determined that student PS11 used ions in symbolic representation in sodium chloride solution and oxygen gas solution. In the interviews after the instruction, it was observed that all pre-service teachers wrote the symbolic representations of the items correctly.

Findings related to the Second Interview Question

In the second interview question, pre-service teachers were asked to decide whether the substances shown in submicroscopic representations were elements, compounds, or mixtures and to explain their choices. The findings of the analysis of these interviews are presented in Table 6.

Table 6. Findings Related to the Second Interview Question (Pre-instruction)

Visual	**Element**		**Compound**		**Mixture**	
	Participant	f	Participant	f	Participant	f
a) 	PS1-PS16	16	-	-	-	-

Visual		**Element**		**Compound**		**Mixture**	
		Participant	f	Participant	f	Participant	f
b)		-	-	PS1, PS2, PS3, PS4, PS5, PS6, PS7, PS8, PS9, PS10, PS11, PS13, PS14, PS15, PS16	15	PS12	1
c)		-	-	PS14	1	PS1, PS2, PS3, PS4, PS5, PS6, PS7, PS8, PS9, PS10, PS11, PS12, PS13, PS15, PS16	15
d)		PS1, PS3, PS5, PS6, PS9, PS12, PS14	7	PS2, PS4, PS7, PS8, PS10, PS11, PS13, PS15, PS16	9	-	-
e)		-	-	PS14	1	PS1, PS2, PS3, PS4, PS5, PS6, PS7, PS8, PS9, PS10, PS11, PS12, PS13, PS15, PS16	15

As seen in Table 6, before the instruction, all pre-service teachers stated that the substance shown in option a, sub microscopically, was an element because it contained only one type of particle. Fifteen pre-service teachers (PS12) stated that the substance in option b was a mixture because it contained two different atoms. Fifteen pre-service teachers stated that the substance in option c was a mixture, while PS14 stated that it was a compound. The pre-service teacher with code PS14 stated that compounds can be formed even when different atoms are not bonded to each other. Regarding the substance in option d, seven pre-service teachers thought it was an element, and nine pre-service teachers thought it was a compound. Pre-service teachers who thought it was a compound stated that it was a compound because the building blocks of matter are molecules, regardless of the type of atom. Regarding the substance in option e, PS14 stated that it was a compound, while the remaining 15 pre-service teachers stated that it was a mixture. The pre-service teacher with code PS14 made a mistake in the interview by stating that when there are different types of atoms, there will always be a compound. After the instruction, all pre-service teachers correctly identified the substance type and explained their choices with correct justifications.

Findings related to the Third Interview Question

In the third question, the pre-service teachers were asked which of the five submicroscopic representations given in the second question could possibly belong to the gaseous substance symbolized as "HI" and were asked to explain their choices. Before the instruction on the substance HI(g), 12 pre-service teachers (PS1, PS2, PS3, PS7, PS8, PS9, PS10, PS11, PS13, PS14, PS15, PS16) chose visual "b" and 4 pre-service teachers (PS4, PS5, PS6, PS12) chose visual "c." The pre-service teachers who chose visual "c" stated that they chose this option because HI(g) is in a gaseous state and because they thought the two types of atoms could not form bonds between them.

After the instruction, all pre-service teachers chose visual "b" and stated that HI(g) is in a gaseous state and is a compound containing only one type of molecule, hydrogen and iodine atoms.

Findings related to the Fourth Interview Question

In the fourth question, pre-service teachers were asked to choose the macroscopic representation of the Br_2(aq) solution whose submicroscopic representation was given and to explain their choices. The findings of the analysis of these interviews are presented in Table 7.

Table 7. Findings Related to the Fourth Interview Question (Pre-instruction)

Option	a (Hydrochloric acid solution)		b (Bromine solution)		c (Mixture of sulphur-iron)		d (Mixture of carbon-chloride potassium)	
	Participant	f	Participant	f	Participant	f	Participant	f
Pre-instruction	PS7, PS9, PS13, PS15	4	PS1, PS2, PS3, PS4, PS5, PS6, PS8, PS10, PS11, PS12, PS14, PS16	12	-	-	-	-
Post-instruction	-	-	PS1-PS16	16	-	-	-	-

As shown in Table 7, before instruction, 12 pre-service teachers stated that the substance was bromine solution, while 4 pre-service teachers stated that it was a hydrochloric acid solution. The pre-service teachers who thought it was a hydrochloric acid solution stated that they had reached this conclusion based on the water molecules in the submicroscopic representation and the idea that the prefix ‘hydro’ means water. At the end of the instruction, all pre-service teachers correctly identified that the given submicroscopic representation belonged to a bromine solution by selecting option 'b'.

Findings related to the Fifth Interview Question

In the fifth question, pre-service teachers were given the submicroscopic representation of the Br_2(aq) solution and were asked to choose the symbolic representation of the solution and explain the reason for their choice. Table 8 presents the results of the analysis of these interviews.

Table 8. Findings Related to the Fifth Interview Question

Option	a ($Br_{2(s)}$)		b ($Br_{2(aq)}$)		c ($Br_2H_2O_{(aq)}$)		d (Br_2 and H_2O)	
	Participant	f	Participant	f	Participant	f	Participant	f
Pre-instruction	-	-	PS1, PS3, PS4, PS5, PS7, PS11, PS13, PS16	8	PS2, PS6, PS8, PS9, PS10, PS12, PS14, PS15	8	-	-
Post-instruction	-	-	PS1-PS16	16	-	-	-	-

As shown in Table 8, prior to instruction, 8 pre-service teachers selected option 'b', while 8 pre-service teachers selected option 'c'. The pre-service teachers who selected option 'b' stated in their explanations that the subscript 'aq' represented the solution. The pre-service teachers who selected option 'c' stated that they thought the term "aqueous" in the question and the subscript 'aq', which means solution, should appear together in the symbolic representation. At the end of the instruction, all pre-service teachers correctly identified that the symbolic representation belonged to a bromine solution by selecting option 'b.'.

Discussion and Conclusion

According to conceptual understanding (Ausubel, 1968), the transition between different chemical representations is a very difficult task. Conceptual difficulty is defined as the inability to relate the three levels of representation (Davidowitz & Chittleborough, 2009). Kozma and Russell (1997) identified the ability to transform representations from one form to another as an important aspect of successful chemistry problem solving. Potgieter et al. (2005) attributed this issue to students' inability to interpret chemical phenomena at the submicroscopic level. Students' difficulties with the symbolic and submicroscopic dimensions may stem from inadequate chemistry knowledge, focusing on the macroscopic dimension during instruction and, most importantly, an inability to access the submicroscopic and symbolic dimensions directly through the senses in daily life (Head et al., 2017; Talanquer, 2011). This phenomenon may be because chemistry teaching is algorithmic rather than conceptual; students only conduct experiments procedurally in the laboratory, and teachers rarely use dynamic and static diagrams appropriate to the three representations in teaching and assessment. The argumentation-based teaching implemented in this study aimed to address precisely this deficiency; it supported this transitional competence by encouraging students to justify ideas about chemical phenomena at submicroscopic and symbolic levels.

Quantitative Results Concerning the Ability of Transitions Between Chemical Representations

According to the statistical results regarding students' proficiency in transitioning between chemical representations, it was observed that there was a statistically significant difference between the students' pre-test ($\bar{X}$= 5.87) and post-test ($\bar{X}$=9.06) results, in favor of the post-test. The effect size (d) of the study was determined to be 1.538, and this value being greater than 0.8 indicates that the teaching had a large effect (Cohen, 1994). This quantitative finding confirms previous literature that has determined that argumentation promotes conceptual understanding and meaningful learning (Güngör-Seyhan & Eyceyurt-Türk, 2022; Yaman, 2019). This observed effect can be attributed to the intense collaboration and discussion environment provided by the argumentation process. Through discussion activities, students can better understand science (Agusty & Chen, 2025). Johnstone's Triangle illustrates three levels of chemical understanding: macroscopic, microscopic, and symbolic. It emphasizes the challenges students face in integrating these representations (Rüschenpöhler, 2020). This complexity necessitates a strong argumentation framework, as students must learn to navigate and connect these three dimensions effectively. This method enables students to make claims, provide evidence, justify their reasoning, and provides an environment for explanation by establishing relationships between the three levels of chemical representation while creating their arguments for the problem under discussion (Yaman, 2019).

Rüschenpöhler (2020) states that the teacher's role in facilitating discussions about these levels can significantly improve students' argumentation skills and understanding of chemistry. The following qualitative findings detail how this process reduces specific conceptual difficulties.

Qualitative Results Concerning the Ability of Transitions Between Chemical Representations

Development in the Ability to Transition to Submicroscopic Representations (Question 1 and 3)

In this section, the difficulties encountered by preservice teachers when transitioning from macroscopic (observable) or symbolic (chemical language) representations to submicroscopic (particle-level) representations will be discussed in light of findings obtained before and after instruction.

The findings from interviews with pre-service teachers before instruction indicate that they experience significant difficulties with submicroscopic concepts, which form the basis of their ability to transition between chemical representations. These difficulties often center around confusing the concepts of atoms, molecules, and ions, neglecting physical states, and misunderstandings about how a single particle constitutes matter. The fact that students use the terms "sodium molecule" for $Na_{(s)}$, "atom" or "molecule" for $NaCl_{(s)}$, "atom" for $H_2O_{(s)}$ and $O_{2(g)}$, "molecule" for $NaCl_{(aq)}$, and "ion" for $O_{2(aq)}$ indicates that they use the terms "atom", "molecule", and "ion" interchangeably. This finding is consistent with the literature suggesting that students struggle to understand fundamental particle concepts (Gkitzia et al., 2020; Pinto et al., 2023; Taber, 2001). A tendency to draw a single particle for substances such as $Na_{(s)}$, $NaCl_{(s)}$, $H_2O_{(l)}$ and $O_{2(g)}$ has been observed among pre-service teachers. This situation indicates that pre-service teachers fail to grasp the discontinuous, particulate nature of matter and cannot establish a connection between the macroscopic (observable) properties of matter and its microscopic structure (Gkitzia et al., 2011). Pre-service teachers, particularly, failed to accurately reflect the ionic lattice structure or regular structure of solids such as metallic sodium and sodium chloride (Vikström, 2014). Furthermore, in their submicroscopic drawings of aqueous solutions (NaCl(aq), O_2(aq)), they have disregarded the presence of water molecules and ion-dipole interactions. The idea of ionization for O_2(aq) points to misconceptions about the dissolution process (Gkitzia et al., 2020). The propensity of pre-service teachers to conceptualize the dissolution of oxygen gas in water as a chemical reaction signifies a misunderstanding that dissolution is a physical phenomenon (Pinto et al., 2023). When transitioning from the symbolic representation HI(g) to the submicroscopic drawing (Question 3), it was observed that some pre-service teachers interpreted the substance HI(g) as a mixture, based on the idea that chemical bonds do not form between atoms in gaseous substances. This finding is consistent with the work of Adbo and Taber (2009), which indicates that pre-service teachers assume that atoms in the gaseous phase move completely independently of each other and therefore tend to deny the existence of bonds even in covalent compounds such as HI(g).

After argumentation-based instruction supported by concept cartoons, significant progress was made in the pre-service teachers' ability in transitioning to submicroscopic representation. Significant improvements have been observed, particularly in the areas of particle type and multi-particle drawing, as well as in gas-phase bonding. The research findings support the idea that establishing a connection between argumentation and chemical representations can improve learning outcomes. Ramadhani et al. (2023) emphasize that students' argumentation skills are closely related to their ability to use chemical representations effectively, and that specific components of argumentation may require specific representational dimensions. In this process, students are compelled to support their claims (e.g., NaCl(s) is a compound, Na(s) metal is an element) with valid and strong evidence (for NaCl(s): ionic bonding, the presence of Na^{+} and Cl^{-} ions; for Na(s) metal: metallic bonding, the presence of Na atoms). During the discussions, when students mentioned NaCl molecules for the ionic compound or sodium ions/molecules for sodium metal in their arguments and/or depicted these in their submicroscopic drawings, it constituted incorrect evidence. Such evidence was readily rebutted by their peers in the debate.

This argumentation process implemented in the classroom ensured students' understanding of fundamental definitions such as atom, molecule, and ion, thereby largely overcoming misconceptions related to particle type and the idea that a single particle constitutes matter in macroscopic-submicroscopic transitions. These results support the literature findings (Yaman, 2019) that the Science Writing Heuristic (SWH) approach, based on argumentation, is effective in enhancing conceptual understanding of fundamental chemistry concepts such as the particulate nature of matter.

The pre-instruction misinterpretation of HI(g) as a mixture was completely corrected post-instruction. All pre-service teachers correctly identified HI as a compound formed by the chemical bonding of two different atoms. This improvement demonstrates that students were successful both in understanding the structural properties of substances in the gas phase and in transitioning from symbolic to submicroscopic representations.

However, difficulties persisted in drawing ionic lattice structures and illustrating ion-dipole interactions after instruction. During the argumentation process, students engaged in discussions facilitated by activities that enabled them to transition between different chemical representations. In these discussions, they made submicroscopic drawings on paper while constructing their arguments. Even presenting submicroscopic representations through short animations or simulations at the end of the process was insufficient to overcome the difficulties experienced by some students. This situation suggests that three-dimensional thinking (Doğan & Demirci, 2011) and the visualization of abstract dynamic processes (dissolution) require longer and more interactive learning experiences (Peterson & Treagust, 1989; Ünal et al., 2006).

In this context, it is critically important for teachers to integrate argumentation with dynamic visual aids to support conceptual change at the submicroscopic level. To overcome these challenges, it may be advisable to integrate computer simulations into the argumentation process in a way that students can work with. Studies have demonstrated that simulations facilitate students' visualization of submicroscopic particles and enhance the interconnections among macroscopic, submicroscopic, and symbolic representations (Davidowitz & Chittleborough, 2014; Hu et al., 2024; Kelly & Jones, 2007). Research demonstrating that virtual chemistry laboratories (Yaman, 2019) and mixed-lab environments offer optimal support for the enhancement of argumentation, representation, and reasoning skills (İnan et al., 2025) robustly endorses this recommendation. When studying dynamic chemical events like ion-dipole interactions, simulations give students a chance to use the system as an experimental tool and interact with rules and causal interactions in a way that physical models don't. This interactive modelling lets students get immediate feedback on how well their drawings or models fit, which helps them quickly correct any wrong ideas they have and make better mental models.

Development in the Ability to Transition to Symbolic Representation (Question 1 and 5)

This section discusses the difficulties encountered by pre-service teachers when transitioning from macroscopic and submicroscopic representations to symbolic representations, focusing on the role of argumentation in clarifying the language of chemistry, in light of pre- and post-teaching findings.

Pre-teaching interview findings indicated that pre-service teachers experienced two primary difficulties in using and interpreting symbolic representation: conceptual ambiguity and errors stemming from incorrect application of symbolic representation rules. The most common error resulting from conceptual ambiguity was confusing the symbols for particles (atoms/molecules) with those for matter (elements/compounds). This difficulty, which Taber (2009) describes as "acquiring a second language," stems from the fact that in the language of chemistry, the same symbol (e.g., "H_2") carries both macroscopic (e.g., "hydrogen gas") and submicroscopic (e.g., "a hydrogen molecule") meanings. This makes it difficult to make conceptual distinctions in the macroscopic-symbolic transition (Gkitzia et al., 2020).

In the category of incorrectly applying rules in symbolic representation, pre-service teachers exhibited errors such as using incorrect charges, incorrect coefficients, incorrect subscripts, and incorrect symbols in symbolic representation. For example, they used "Na^+Fe^-" for metallic sodium, "$Na^+Cl_{(s)}^-$ or $NaCl_2$" for sodium chloride, "“$O_2H_2O_{(aq)}$ or $H_2O_{2(aq)}$” " for oxygen solution, and "$O_{(gas)}^{+2}$" for oxygen gas. These findings indicate that pre-service teachers confuse the use of subscripts and coefficients in symbolic representation. Furthermore, these findings reflect serious misconceptions among some pre-service teachers, such as thinking of dissolution as a chemical reaction (thinking that hydrogen peroxide is formed by reacting oxygen gas with water). Similar findings are available in the literature (Gkitzia et al., 2020; Naah & Sanger, 2012; Nyachwaya et al., 2011). Naah and Sanger (2012) found that students believed that subscripts changed not only the atomic number but also the charge of the ion, and they confused them with coefficients. Furthermore, half of the students answered incorrectly when asked to choose the symbolic representation of the $Br_{2(aq)}$ solution, believing that the term "aqueous" should be represented symbolically as "$Br_2H_2O_{(aq)}$." This suggests that pre-service teachers did not fully grasp the meaning of parenthetical representations and subscripts (aq) at the symbolic level.

Following lessons based on concept cartoon-supported argumentation, it was observed that pre-service teachers experienced less difficulty transitioning between different levels of representation and achieved complete success, particularly in the submicroscopic-symbolic transition (e.g., selecting the correct symbol to represent $Br_{2(aq)}$ solution). This result is consistent with empirical findings (İnan et al., 2025) indicating that students' written argumentation, use of multiple representations, and reasoning skills develop in parallel. In the argumentation process, students must use symbolic representation (the formula) to support a claim (e.g., ‘This substance is a compound’). An incorrect formula (e.g., writing $NaCl_2$ instead of $NaCl_{(k)}$) creates chemically invalid and incorrect evidence and weakens the claim. And this evidence is easily refuted by other students participating in the discussion. The ease with which evidence can be refuted and the necessity of verifying the evidence presented compels students to learn the precise meanings of subscripts, coefficients, and charges and to apply them correctly. Students' ability to avoid difficulties with symbolic representations depends on the use of clear and consistent language in the teaching process. Argument-based teaching requires, as in the example below, that it be clearly emphasized which level of representation (e.g. element, substance, atom or molecule) symbolic representations correspond to.

For example, when using the term “hydrogen”, it should be clearly emphasized whether it refers to an element (H), a substance (H_2 gas), an atom (H atom) or a molecule (H_2): *“Ethane contains fewer hydrogen atoms than ethane.”* (Atom emphasis), *“Hydrogen gas (H_2) burns with a hissing sound.”* (Substance emphasis)" (Taber, 2014; p.102).

In discussions, students must provide reasons for the meaning of a symbol when selecting evidence to support their claims and explaining the relationship between them. This justification has played a critical role in minimizing conceptual ambiguities and establishing a solid link between macroscopic/microscopic levels and symbolic levels. In light of these findings, in chemistry teaching, teachers must directly explain which level of representation symbolic representations correspond to and provide examples that minimize conceptual ambiguities in order to support the learning of symbolic representations.

Development in the Ability to Transition to Macroscopic Representation (Question 2 and 4)

This section addresses the difficulties pre-service teachers encounter when transitioning from submicroscopic representations to macroscopic (observable and classifiable) properties, based on pre- and post-teaching findings.

The findings prior to instruction show that pre-service teachers mainly made errors in correctly classifying basic types of matter (element, compound, mixture) and in interpreting aqueous solutions during the submicroscopic-macroscopic transition. When examining their errors related to types of matter, preservice teachers correctly identified the atomic element representation (image a) but made errors in the molecular element representation (image d). Preservice teachers who made the error confused a molecular element with a compound. This misconception may stem from the belief that a bond formed by the combination of the same or different atoms forms a compound (Doymuş et al., 2009; Gkitzia et al., 2011). Such an error may stem from preservice teachers' failure to establish the relationship between the diversity of atomic types and the types and presence of bonds. Some preservice teachers interpreted a mixture of atoms (image c) and a mixture of molecules (image e) as compounds. This error reflects the difficulties in transferring the existence of chemical bonds at the submicroscopic level and the distinction between pure substances and impure substances to the macroscopic level of classification. In the transition from the submicroscopic to the macroscopic representation of the $Br_2(aq)$ solution, some prospective teachers saw water molecules and assumed the substance was a hydrochloric acid (HCl) solution. This error demonstrates that the pre-service teachers made a mistake by incorrectly connecting the prefix "hydro" to water without considering the bromine molecules present in the submicroscopic representation.

Following argumentation-based teaching, significant progress has been recorded in pre-service teachers' abilities to interpret submicroscopic representations and classify them correctly at the macroscopic level. In particular, misconceptions about the differences between elements, compounds, and mixtures have been largely eliminated. When presenting an argument as to why a submicroscopic image was an element or not a compound, students had to support their claims with evidence consistent with chemical definitions (a single type of atom, a molecule composed of different types of atoms, and the presence or absence of chemical bonds). This process enabled them to understand the subtle differences in the submicroscopic definition of an element (atomic or molecular?) and ensured that misconceptions such as molecular element-compound confusion were corrected through peer discussions. This result is consistent with findings in the literature indicating that argument-based teaching enhances conceptual understanding (Adadan & Savasci, 2012; Özmen, 2013).

After instruction, all pre-service teachers identified the correct macroscopic representation for the $Br_2(aq)$ question based on submicroscopic and symbolic representations (e.g., bromine molecules, aqueous solution). This shows that pre-service teachers can both holistically analyze molecular-level visuals and establish consistent connections between chemical symbols and macroscopic properties (e.g., based on bromine molecules and aqueous solution).

The ability to accurately classify macroscopic phenomena based on submicroscopic representations is a key indicator of conceptual understanding in chemistry education. This success demonstrates the effectiveness of argumentation-based instruction in addressing misconceptions about matter and chemical species. Therefore, to further develop students' transitional competence and ensure lasting learning, it is crucial for teachers to explicitly integrate the three levels of chemical representation into the course and systematically emphasize the relationships between these levels. Literature indicates that for students to achieve lasting learning, they must explicitly relate macroscopic phenomena to microscopic particles and symbolic representations such as formulas (Santos & Arroio, 2016). Teachers should always incorporate submicroscopic definitions as a strategy when classifying, especially for topics such as pure substances and mixtures, to prevent students from making erroneous inferences based on macroscopic observations.

Textbooks are the primary resources used by teachers in the lesson planning process (De Jong et al., 2005). Most teachers plan their lessons based on the content of textbooks (Akaygün, 2018). Şendur (2021) examined representations in organic chemistry textbooks and emphasized that verbal and symbolic explanations alone are insufficient for teaching abstract concepts; he highlighted the importance of rich and explanatory visuals in textbooks. However, the existence of these multiple representations alone is not sufficient. Teachers should not present these representations passively; rather, they should actively integrate them into teaching processes such as argumentation. Teachers should encourage students to transition between these representations and establish relationships between them to support or debate their claims.

As a result, argumentation-based instruction supported by concept cartoons, due to its reliance on intensive collaboration and discussion, enhanced preservice teachers' ability to transition between chemical representations. Students engaged in cognitively challenging processes during discussions, including finding evidence to support their claims, explaining their reasons, and refuting alternative perspectives. During this process, preservice teachers were encouraged to collaboratively analyze different levels of representation (macro, micro, and symbolic) and develop solution strategies to relate them. Furthermore, consistent with the positive effects of collaboration in heterogeneous groups, this discussion environment, based on peer interaction, enabled individuals experiencing initial difficulties to benefit from within-group knowledge sharing and continuous feedback. This approach enabled concepts to be considered from different perspectives, quickly identified misconceptions, and fostered conceptual change. Preservice teachers developed a deeper conceptual understanding of translating between macro, micro, and symbolic levels. This finding shows that argumentation is a powerful pedagogical tool for overcoming challenges encountered in transitioning between chemical representations.

Limitations of the Present Study

The primary limitations of this study relate to the sample and research design. The study was conducted with a relatively small (N=16) and accessible sample of pre-service biology teachers studying at a university in the western region of Türkiye. The sample's numerical limitations and homogeneity restrict its generalizability to larger populations, diverse geographic regions, and student levels.

Another significant limitation is the lack of a control group. Due to the single-group pretest-posttest design employed in the study, the potential impact of factors compromising internal validity—such as recall bias resulting from repeated testing—could not be completely excluded from the observed improvements between measurements.

Another limitation is the relatively short duration of the instructional intervention, which lasted only 7 weeks. The seven-week implementation period enabled us to achieve significant findings within the scope of this study. However, it is recommended that future longitudinal or longer-term experimental studies be conducted to further investigate how transition competencies between chemical representations change and persist over time.

Notes

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